

Spacecraft Health Automated Reasoning Prototype (SHARP)

The Fiscal Year 1989 "SHARP Portability Evaluations" Task for NASA Solar System Exploration Division's Voyager Project NASA Ames Research Center Telescience Testbed Program

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August 15, 1990



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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PREFACE

The purpose of this document is to provide a brief report on a SHARP portability studies task conducted for, and funded jointly by, the NASA Solar System Exploration Division's Voyager Project and for the Telescience Testbed Program managed by NASA Ames Research Center. It is intended as a companion document to an additional report called "A Report on SHARP and the Voyager Neptune Encounter" (JPL Publication 90-21) which describes the development and application of the Spacecraft Health Automated Reasoning Prototype (SHARP) for the operations of the telecommunications system and link analysis functions in Voyager mission operations. This report is intended primarily for technical and program managers in the area of mission operations automation for spacecraft and telescience applications, and describes some specific progress on the portability studies for the JPL Space Flight Operations Center, plans for technology transfer, and potential applications of SHARP and related artificial intelligence technology to telescience operations. The companion report provides an overview of the design and functional description of the SHARP system as it was applied to Voyager.

The application of SHARP to Voyager telecommunications was a proof-of-capability demonstration of artificial intelligence as applied to the problem of real-time monitoring functions in planetary mission operations. SHARP has provided us with an excellent example of how advanced artificial intelligence techniques can be smoothly integrated with a variety of conventionally programmed software modules, as well as guidance and solutions for many questions about automation in mission operations. From a broader, operational perspective, SHARP has shown that a large set of mission operations functions in the area of real-time monitoring of spacecraft health and status can be effectively automated, with significant payoffs in the areas of safety, work-force savings, personnel productivity, and system reliability. These payoffs are discussed in the companion report.

SHARP has received widespread attention in the press, ranging from mass news media to highly technical journals. News articles about SHARP have appeared in *Information Week Magazine*, *AI Week*, *Computerworld*, *Computers and Physics Journal*, *Federal Computer Week*, *Symbolics Symposium*, *IEEE Expert*, *IEEE Spectrum*, *Government Executive Magazine*, *Insight*, *Aerospace Engineering*, *The Washington Times*, *The New York Times*, *The Los Angeles Times*, *Nikkei Artificial Intelligence* (Japanese publication), and the *Journal of Commerce*. While this level of attention is

certainly exciting, it also indicates the importance that both technologists and users are attaching to effective applications of artificial intelligence.

The SHARP application to Voyager telecommunications was conducted as part of a long-term research and development task being conducted for the NASA Office of Aeronautics and Exploration Technology (OAET) Artificial Intelligence Program called "Ground Data Systems Automation." This task, which began in October 1987, has the on-going objective of developing and demonstrating automation technologies which enable and enhance multimission capabilities of operations ground systems for planetary spacecraft and for the Deep Space Network (DSN).

Currently, under joint sponsorship of the NASA OAET Artificial Intelligence Program and JPL Flight Projects Support Office, a SHARP "shell" is being readied for transfer to the Space Flight Operations Center (SFOC) in the summer of 1990, where it will be used beginning in August for the Magellan spacecraft's telecommunications operations. At that time, the SHARP shell will be fully compatible with the SFOC environment, meet SFOC user interface and data interface requirements, and be in compliance with JPL software standards for flight software. This shell will be a major component of a multimission spacecraft performance analysis tool set which the Flight Project Support Office will develop. Additionally, the JPL Deep Space Network's Office of Engineering is applying SHARP technology to telecommunications link performance analysis as part of the Network Operations Control Center (NOCC) upgrade, scheduled for operations in 1991.

With the success of the application for Voyager telecommunications, and follow-on tasks under way which will carry the technology forward into operational systems, we feel that the major objectives set for SHARP have been achieved and that there are now opportunities for multiple applications of artificial intelligence in planetary mission operations and telescience operations of the future.

David J. Atkinson
JPL, April 4, 1990

ABSTRACT

This document provides a report on a SHARP portability study. It describes some specific progress on the portability studies for the JPL Space Flight Operations Center, plans for technology transfer, and potential applications of SHARP and related artificial intelligence technology to telescience operations.

The application of SHARP to Voyager telecommunications was a proof-of-capability demonstration of artificial intelligence as applied to the problem of real-time monitoring functions in planetary mission operations. A companion report (JPL Publication 90-21) provides an overview of the design and functional description of the SHARP system as it was applied to Voyager.

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1. Overview of Code EC/EL FY89 Activities

Work on SHARP in fiscal year 1989 under funding from Codes EC and EL was aimed at achieving the following two objectives:

1. Help achieve compatibility for SHARP with SFOC.
2. Help achieve portability of SHARP to SFOC and other computing environments such as those which might be part of a telescience application.

These objectives were addressed through the following activities:

1. Providing a preliminary plan for a complete porting of SHARP to an SFOC environment and delivery to a baseline SFOC. The plan addresses/includes:
 - Close integration with SFOC over the long term.
 - Plans for modifications to SHARP for portability, maintainability, and performance.
 - Plans for the delivery of hardware, testing, documentation, and training.
 - Schedules for development and integration which mesh with SFOC and flight project user requirements.
2. Participating in the SFOC user-interface requirements working group.
3. Demonstrating the performance of some of the significant modules of SHARP on an SFOC-compatible SUN workstation with Symbolics Ivory board installed.
4. Evaluating the performance of the ported modules, including profiles of CPU time, memory requirements, file system access, and other measurements.

The next section of this document gives a summary of SHARP and its use during the Voyager encounter with Neptune. This is followed by sections that expand on the set of activities described above.

The document concludes with some remarks on how SHARP can support scientific instrument monitoring and, more generally, how AI technology can support telescience.

2. Overview of SHARP and the Voyager-Neptune Demonstration

The Spacecraft Health Automated Reasoning Prototype (SHARP) introduces automation and artificial intelligence technologies to the process of monitoring spacecraft operations. One of the goals of SHARP is the elimination of much of the mundane processing and tedious analysis currently required of operations personnel. Another goal is to provide faster and more reliable identification of errors that occur during a spacecraft mission than is currently available. The major automated functions provided by the SHARP system include:

- Real-time anomaly detection and diagnosis;
- Visualization of channelized data and system status;
- Acquisition and centralization of operations data in a single workstation, including real-time spacecraft and ground system engineering data, sequence of events, and alarm tables;
- Real-time analysis of spacecraft performance predictions;
- Integration with specialized numerical analysis software, e.g., fast Fourier transforms for determining spacecraft antenna pointing accuracy.

The SHARP prototype was developed for use in the Voyager telecommunications (telecom) monitoring area. The SHARP system provides telecom personnel with an environment that allows them to have a more complete understanding of how the telecommunications link is functioning between a spacecraft and the Deep Space Stations (DSS). Deep Space Station sites are located at Goldstone, California, Madrid, Spain, and Canberra, Australia, and collectively form the Deep Space Network (DSN).

The SHARP environment contains the necessary data to allow SHARP to oversee the expected behavior of the spacecraft and Deep Space Stations it is monitoring. It also receives real-time data which reveal how these systems actually are performing. If the real-time

data fail to correlate with the expected behavior, SHARP informs the operator responsible for the monitoring operation that an alarm condition exists. It also lists the potential causes for this anomaly and suggests what actions to take to respond to the alarm condition. In SHARP, the automation of fault detection and diagnosis is accomplished through the use of artificial intelligence programming techniques. Artificial intelligence techniques are distributed throughout all components of the SHARP system. Artificial intelligence programming methodologies have enabled more effective automation and thorough analysis by SHARP functions. In addition to having complete access to all of the relevant data which allow SHARP to perform its necessary analysis functions, the SHARP system contains an extensive collection of graphical displays. These displays give the operations personnel a comprehensive view of the status and dynamics of the systems that they are monitoring.

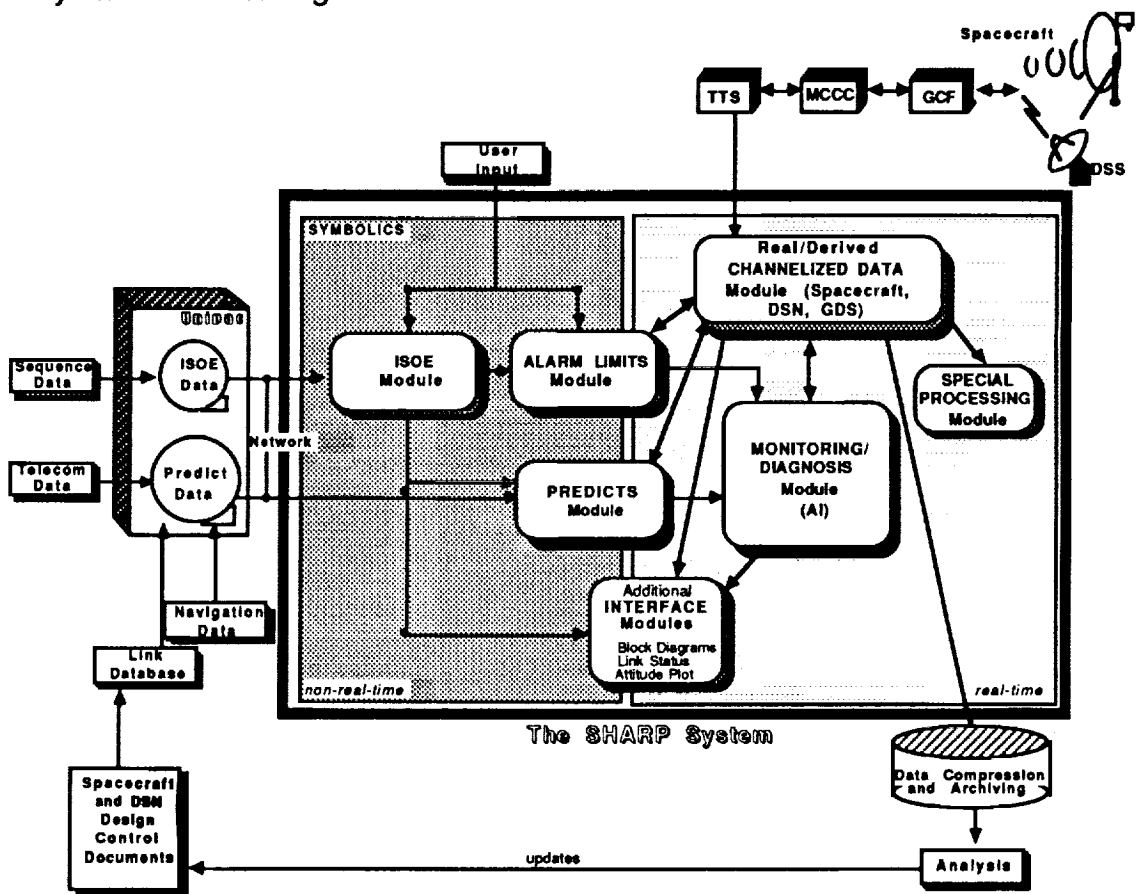


Figure 1. SHARP System Overview

Figure 1 illustrates a top-level view of the SHARP system. Shown are the individual modules that compose the system, as well as relevant components that are external to the Voyager application of SHARP. SHARP is implemented in Common Lisp on a Symbolics 3650 color Lisp Machine. The system is currently being ported to a Sun workstation, also running Common Lisp. SHARP relies extensively on an expert system building language called STAR*TOOL, developed at JPL.

2.1. Inputs

In order for the SHARP prototype to analyze the telecommunications link from the spacecraft through the Deep Space Network and ultimately to the computers at JPL, a wide variety of information and data must be accessed and processed. Some data and knowledge are acquired before operational use and are stored in databases or are encoded within the SHARP program. Other data are collected in real time during operational use.

The following gives a short description of the data. Figure 2 gives a summary of the source of each type of data, where the data are encoded in SHARP, and who has the capability to modify the data.

Data	Source	Location in Sharp	Modifiable by
Predicts	Univac Text File	Database	N/A
ISOE	Univac Text File	Database	User
Channelized Data	Real Time	Database	N/A
Alarm Limits	Domain Expert	Data Tables	User
Rules	Domain Expert	Code	Programmer

Figure 2. SHARP Input Data

Predicts

These are predictions of values for spacecraft and Deep Space Network station parameters based on numerical models of system performance.

Integrated Sequence of Events (ISOE)

This is a time-ordered sequence of scheduled spacecraft and Deep Space Station activity. Examples of these include: specifications regarding timing and the transmitter power and frequency at the Deep Space Station for uplink commands being sent to the spacecraft, when the spacecraft is performing maneuvers, and the state of the receivers and transmitters on the spacecraft. Last minute corrections, additions, or deletions to these events can be made by the operator.

Channelized Data

These are real-time engineering data that contain information regarding the status of systems both on board the spacecraft and at the DSSs.

Alarm Limits

These are minimum and maximum values that specify the boundaries of the nominal values for engineering data. Error conditions, i.e. alarm states, occur when the engineering data exceed these limits. Changes to these limits can be made by the operator in response to planned spacecraft state changes as well as unforeseen changes in the behavior of the systems being monitored.

Rules

These contain knowledge of how the various systems that SHARP is monitoring should behave and interact. These rules use that information and the data described above to determine the existence of either simple or complex error conditions, and to give hypotheses regarding the causes of these errors.

2.2. Processing

There are several kinds of processing which occur within the SHARP system. These are:

- Capturing the real-time channelized data and storing them in a database,
- Using conventional and artificial intelligence techniques to analyze the real-time data for the occurrence of alarm conditions,
- Determining probable causes and responses to alarm conditions, and
- Displaying data and management of the various displays.

SHARP runs in a multiprocessing environment with interactions among the different kinds of processing.

2.3. Outputs

The primary purposes of the SHARP system are to provide a better operational environment for monitoring various spacecraft and Deep Space Station systems, to warn an operator if there is an alarm condition in the systems that SHARP is monitoring, to assist the operator in determining the cause of an alarm, and to suggest actions to take in response to an alarm. The means used to communicate this information consist of a number of displays, each designed to handle a specific task. Secondly, SHARP also stores the results of some of its processing in log files and databases. SHARP is not an autonomous system in that it takes no control actions of its own. A human is "in the loop" at all times.

The displays of SHARP provide access to data resident in the system, provide an interface to allow the operator to change that data when appropriate, and dynamically indicate alarms and what systems are affected by them. The displays are summarized in Figure 3 and the text that follows.

Display Name	Functionality
Alarm Warnings Attitude and Articulation Control Block Diagrams Channelized Data Plots Fast Fourier Transform Link Status Alarm Meters	Indicate System Status and Alarm Conditions
Alarm Limit Tables Integrated Sequence of Events	Display Data and Accept User Modifications
Channelized Data Monitoring Predicts Alarm History	Show Data or SHARP Status Information

Figure 3. SHARP Displays

Alarm History

This is a scrolling text display that shows all warnings given by SHARP during a session.

Alarm Limit Tables

This is a tabular display that presents the operator with the values of the alarm limits. The operator can modify alarm limits and other parameters using this interface.

Alarm Meters

This display is a collection of meters that show which channels are currently in alarm, and give the time of the last data value that caused the alarm.

Alarm Warnings

This is not actually a display, but a pop-up window that will appear whenever a warning message is given. This window will appear regardless of the primary SHARP display being viewed by the operator.

Attitude and Articulation Control

This display combines spacecraft motion parameters (pitch, yaw, and roll) and records spacecraft movement over time in an iconic display of spacecraft attitude.

Block Diagrams

This collection of displays based upon functional schematic block diagrams allows the user to view the current, instantaneous operational state of components of the communication path from the spacecraft through the Deep Space Stations.

Channelized Data Monitoring

This display is primarily for the SHARP system implementors to allow them to examine activity regarding the real-time data acquisition and database transactions.

Channelized Data Plots

This collection of displays gives graphical views of the collected real-time channelized data plotted in a variety of formats.

Fast Fourier Transform

This display shows the result of a fast Fourier transform (FFT) computation on a selected monitor data channel. An FFT is computed on the signal strength of the spacecraft transmissions received by a Deep Space Station. By being able to examine the relative magnitude of one component of this FFT, the SHARP system helps to determine when there is an antenna pointing problem at the Deep Space Station that is tracking the spacecraft.

Integrated Sequence of Events

This display allows the operators to search for and review summaries of selected events from the Integrated Sequence of Events (ISOE) that affect telecom operations. It also

allows them to update the SHARP ISOE database to reflect the actual real-time commands sent to the spacecraft.

Link Status

This display shows Deep Space Station antenna assignments, uplink and downlink transmissions, and data rates for those transmissions. This display also helps the operators to predict when data quality may be degraded. In contrast to the block diagrams which show the instantaneous status, the Link Status display shows status over time.

Predicts

This display presents the predict information to the operator in a tabular form, and shows DSS view periods for the spacecraft in a graphical time-line format.

2.4 Results of the Voyager-Neptune Encounter

SHARP was evaluated by Voyager operations personnel during the Neptune encounter over a period of approximately 480 hours of operational testing. During this period, the facilities within SHARP helped operators find the cause of, and solve, a Voyager science data error anomaly which appeared in the telemetry from the spacecraft as an excess error count.

The general nature of the response from operations personnel during this testing period was very positive. It reinforced the perception that technologies such as SHARP can give value and benefit to spaceflight operations.

3. Transferring SHARP to JPL's Space Flight Operations Center

A team comprising SFOC and SHARP developers has prepared a conceptual plan for the integration of SHARP technology into SFOC. Under this concept, the SHARP system would be phased into the SFOC environment, thereby achieving the dual objectives of quick availability of the technology within SFOC and an ultimate "harmonious" integration. The focus was on the technical issues involved to demonstrate the feasibility of introducing SHARP into SFOC. Topics such as requirements of specific flight project applications, schedules, and costing were deferred.

Further study indicated that it is convenient to consider SHARP in two parts. The first part effectively constitutes a reusable "shell" or "skeleton." It consists of those portions of SHARP that are essentially independent of the particular subsystem being monitored. The second part consists of the application-specific knowledge for a particular subsystem of a particular flight mission. This latter part is less sensitive to the environment and platform used to support SHARP.

During the Voyager encounter with Neptune, the SHARP developers concluded that the Genera operating system is insufficiently responsive for the operational use of SHARP, particularly with respect to displays. They decided to reimplement the user interface using a more efficient, more portable graphics kernel. This effort is in progress as part of the continued SHARP development.

Although long range plans for SHARP application continue to evolve, two specific work units have been identified, funded, and planned. The "SHARP Technology Transfer" effort will deliver SHARP to the SFOC environment. The "Application of Automated Spacecraft Health

Monitoring" effort will apply SHARP to monitoring the Magellan telecommunications subsystem as an operational demonstration.

The SHARP Technology Transfer work unit will initiate the process of making the technology embodied in SHARP available for support of space flight operations. Specific objectives are to:

1. Provide expert system capabilities for monitoring spacecraft health in the SFOC environment in a manner that utilizes SFOC data sources and operates gracefully with other SFOC features.
2. Achieve levels of robustness and operability required for operational software and comply with appropriate SFOC and JPL standards for deliverable, software-intensive systems.
3. Prepare for subsequent application of SHARP to telecommunications link performance analysis for Magellan and Galileo, for performance monitoring of other types of spacecraft subsystems, and for potential support of the Engineering Analysis Subsystem Environment (EASE).

The approach will be to modify and enhance the existing SHARP Voyager Telecommunications Subsystem demonstration prototype to produce a reusable software component. The target platform will be workstations of the same type and operating system as those used by SFOC. Negotiations with the SFOC project management resulted in the determination that SHARP is to be integrated into SFOC's operational pilot environment. This is an instance of the SFOC system that is being established in parallel with the baseline SFOC. It is intended to serve as a test-bed to allow new technologies to be evaluated in depth prior to their inclusion in the SFOC baseline. Integration into the pilot environment will allow SHARP to be used under operational conditions with actual engineering and monitor data.

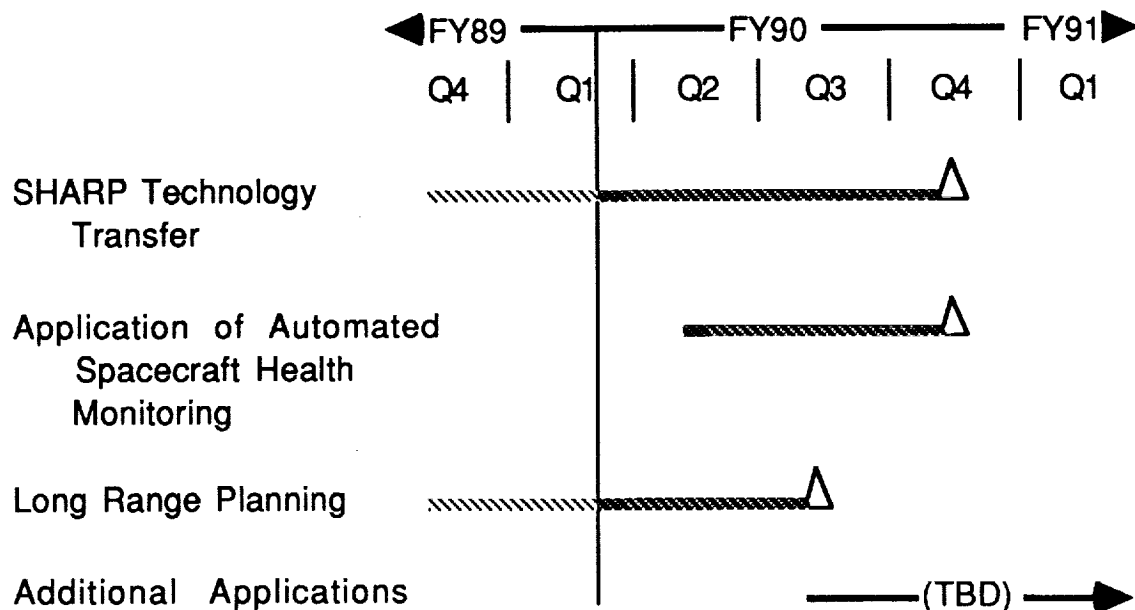
This work is in progress. It is planned to be completed in the summer of 1990. It is sponsored by the OAST Artificial Intelligence program through JPL's Knowledge Systems subprogram.

The Application of Automated Spacecraft Health Monitoring work unit will further demonstrate the feasibility of shifting much of the burden of routine interpretation of spacecraft engineering data from a human operator to intelligent software. This will facilitate continuous monitoring without degradation of performance due to operator fatigue or inattention. The analysis of unusual or emergency conditions will be facilitated by the ability to quickly present the information at an appropriate level of abstraction. The effectiveness of monitoring will be further enhanced by providing each operator with access to cumulative knowledge that is otherwise restricted to a few experts.

The approach will be to apply the reusable, SFOC-based version of SHARP to the Magellan Telecommunications Subsystem. SHARP will be operated in parallel with existing monitoring tools and procedures in support of planetary operations.

This work is scheduled to begin in early 1990 and to be completed the following summer. It is part of the Mission Operations and Data Analysis Technology Initiative.

Schedule



Conclusions

The effort in FY90 will result in an SFOC-hosted capability for intelligent monitoring and diagnosis of the Magellan Telecommunications Subsystem. This version of SHARP will have the following specific characteristics:

1. It will execute in an SFOC-compatible workstation environment;
2. It will have an SFOC-compatible user interface;
3. It will operate on SFOC-generated data;
4. It will be sufficiently robust to be beneficial to operations.

Once this capability is in place, it will be necessary to gain sufficient operational experience with it to test its accuracy and completeness in recognizing and diagnosing telecommunication system errors.

SHARP has the immediate potential to be applied to a broad range of systems that exhibit multifaceted behavior. It can be usefully applied to the monitoring and diagnosis of the state and quantitative attributes of many individual spacecraft subsystems (e.g., Attitude and Articulation Control, Power, and Propulsion), of individual instruments, and of ground and spaceborne computing and communications systems (e.g., the Network Operations Control Center and SFOC itself). With further research, it should also be possible for SHARP applications to cooperate and thus provide multiple layers of visibility into these systems.

4. General Issues In Porting SHARP to SUN/IVORY

The purpose of this task was to port and evaluate portions of SHARP to a SFOC-compatible SUN workstation to help provide guidelines for modifications of SHARP necessary to enhance its portability and performance in alternative delivery environments.

The activities for this task included:

- The demonstration of the performance of some of the significant modules of the SHARP system on a SFOC-compatible SUN Workstation with the Symbolics Ivory board installed.
- The evaluation of the performance of the ported modules, including profiles of CPU time and memory requirements, file system accesses, and other measurements to be determined.

4.1 Discussion

The Ivory is an add-in coprocessor board for SUN 3 and SUN 4 VME-based workstations that allows users to run the Symbolics Genera operating system within the Unix environment. The Ivory-based products are source-code compatible with all programs developed in either Common Lisp or on any Symbolics Lisp Machine. The board is based on Symbolics' Ivory microprocessor technology.

Our tests were performed on a black and white SUN 3 workstation configured with 8MB of physical memory on the SUN processor and 12MB of physical memory on the Ivory Lisp coprocessor. The Symbolics 3650 machine was configured with 24MB of physical memory and included a 8-bit CAD buffer II card.

The Ivory board was evaluated by a series of tests that were designed to test its computational speed in the following areas: graphics output, file I/O, general purpose processing in the average

case, and raw computational throughput. The identical source code was run on each machine. The results of the tests are as follow:

Test 1: Graphics Output Speed

This test was designed to determine the speed of the graphical interface between the Ivory board and the SUN workstation running XWindows. The test involved the drawing of several thousand points and vectors on a black and white screen. The Symbolics 3650 took 2 seconds to complete the task on its color screen whereas the Ivory took 3 seconds on its black and white screen.

It is believed that if the program were re-coded to specially run on the Ivory processor, the Ivory would run at least three to four times faster. The reason that the Ivory ran slower was because the graphics calls went through four levels of indirection before finally executing the call on the SUN workstation. The program could have been rewritten to require only two levels of indirection.

Test 2: File I/O Processing

This test was designed to determine the speed of performing file I/O on the Ivory. The test involved running the SHARP database storage retrieval system.

The Symbolics 3650 took 3 seconds to complete the task whereas the Ivory took 8 seconds.

The Ivory took longer to execute because all file I/O from the Ivory required two levels of indirection before the I/O was actually performed on the SUN workstation. It is not believed that this test could have been made to run faster by specially rewriting the code to run on the Ivory.

Test 3: General Purpose Processing

This test was designed to determine the speed of performing general purpose Lisp processing on the Ivory. This test involved running an existing AI program called STAR*TOOL. STAR*TOOL contains more than one-hundred thousand lines of Common Lisp code. Several STAR*TOOL programs were used for the test. Each test tried various capabilities of the STAR*TOOL system while also checking for correct results.

The Symbolics 3650 took 8 seconds to complete the task whereas the Ivory took 25 seconds.

Test 4: Raw Computational Throughput

This test was designed to determine the raw computational throughput of the Ivory. The test ran exclusively within the cache of the Ivory without generating any page faults to expose the difference between general purpose processing and raw throughput. This test consisted of the execution of a series of loops whose bodies were simple math operations.

The Symbolics 3650 took 20 seconds to complete the task whereas the Ivory required 73 seconds.

The Ivory processor lived up to its claims of being 100% source-code compatible with the Symbolics product line. Between all the tests, over 150,000 lines of Lisp code were recompiled to run on the Ivory coprocessor without any errors.

4.2 Conclusion

The overall conclusion drawn from the four tests is that the Ivory processor running on a SUN workstation runs about 2.7 times slower than a Symbolics 3650 Lisp Machine.

In the near future we will also be running the identical tests on a MAC IIx configured with an Ivory board. We are told that the MAC Ivory runs much faster than a SUN Ivory because of a larger cache on the MAC Ivory board.

The implications of this result are that the SUN Ivory combination does not provide the necessary hardware performance to run SHARP and provide the necessary real-time analysis of data. However, initial tests have shown that if SHARP were translated to run directly in a SUN 4 native operating environment (without translating SHARP from Common Lisp) that it would run several times faster than its Symbolics 3650 version. We feel this is the solution to take.

5. Future Work

5.1 SHARP for Instrument Monitoring and Telescience

The utility of the SHARP system as a monitoring and diagnosis workstation was demonstrated for the Voyager telecommunications subsystem during the Neptune encounter during August 1989. SHARP has been designed from the outset for multimission and multisubsystem applicability in consonance with the charter for JPL's Space Flight Operations Center.

A potential application area for SHARP is the monitoring of scientific payloads -- both specific experiments and the communications links required to support telescience. SHARP provides a diverse set of capabilities for monitoring science activities on platforms such as Space Station Freedom, the network of satellites envisioned in the Earth Observing System, and remote ground sites like Greenland and Antarctica. These capabilities include: predict generation, dynamic alarm limits, sequence of events browsing, real-time channelized data display and analysis, system-level status monitoring, real-time knowledge-based fault diagnosis and recovery advice, continuous supervision, a graphics-oriented user interface, and specialized analysis functions.

Using SHARP to support telescience would provide the benefits of increased reliability regarding the scientific research being conducted and the instrumentation supporting that research. There could also be increased productivity by the individuals monitoring the experiment.

SHARP, used by an investigator to remotely monitor a scientific experiment, would be able to follow the progress of the experiment in terms of the experimental protocol being used and the scientific data being generated. SHARP could receive engineering sensor data

from the equipment necessary to run an experiment and determine whether it matched expected operational performance. For example, SHARP could monitor the output voltage and current on a power supply to determine if it had been turned on at the appropriate time and if it was delivering the proper value of power as specified by an experimental protocol. If the measured data did not agree with the operational plan, the scientist could be alerted by SHARP to this discrepancy. SHARP could also receive science data from equipment that was monitoring the result of an experiment. If the scientist perceived that the experiment was not progressing well, he could change the experimental protocol in response to that information. Finally, if SHARP were programmed with the knowledge of the protocol and the expected results of an experiment, it could reason about either the engineering data or the science data being received. This capability would allow the experiment to be monitored by an operator with less knowledge about its behavior, freeing the primary investigator for more important tasks. However, the safety would not be impaired as SHARP would be able to alert the operator of anomalous behavior and to give the operator recommendations of potential responses to the anomalies.

Many experiments require constant supervision to guarantee that they progress normally. If such an experiment were placed on board the Space Shuttle or Space Station Freedom, it might require an astronaut to do this supervision. This effort would take valuable time away from other activities that the astronaut could be performing. A scientist on the ground, monitoring the experiment remotely with the assistance of a SHARP system, would free the astronaut to do other tasks.

5.2 Other AI for Telescience

SHARP shows potential for helping to increase the amount of scientific return that can come from space exploration and telescience. Two other areas of investigation within the Artificial Intelligence Group at JPL could complement SHARP and also increase the knowledge gained from endeavors in telescience. These are in the fields of scheduling and scientific data analysis.

AI technology can support telescience in scheduling and resource allocation for scientific experiment operations. There is often a need to reconfigure an experiment within a short time frame due to unexpected results, transient opportunities, or changes in onboard resources to support the experiment. The AI Group at JPL has developed an automated scheduling system known as Operations Mission Planner (OMP). This system is based on interleaved, iterative refinement and heuristic control of search and was inspired by observing Voyager mission specialists. OMP was designed to address the goal of handling unexpected events with minimal disruption to an existing schedule. Research results from the OMP task currently are being transferred to Space Station Freedom scheduling domains in collaboration with Johnson Space Center. The goal in this work is to combine autonomous scheduling with interactive scheduling tools to provide an automated scheduling capability which can be invoked and guided by ground-based operations personnel. This capability is applicable to remote configuration/reconfiguration of spaceborne scientific experiments.

Another area where AI-based techniques can support telescience is data analysis. JPL's AI Group also is working on a task known as Scientific Analysis Assistant (SAA) which addresses the storage, manipulation, analysis, and visualization of scientific data. Some of the specific objectives of this task include developing a data manipulation and presentation language to allow the investigator to

access and perform transformations on data and present it in an informative format, providing an integrated toolbox of AI-based analysis and simulation tools, and developing an intelligent library facility for the storage and retrieval of analysis functions. Longer-term objectives include providing a capability for flexibly composing and/or creating data filters for abstracting large volumes of data, and the use of user modeling techniques to infer investigators' analysis goals so that the SAA may suggest related data sets and appropriate analysis tools. The goal of this work is to provide scientist users with desktop, graduate-student level assistance in analyzing and interpreting data from remote scientific instruments.

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16. Abstract This document provides a report on a SHARP portability study. It describes some specific progress on the portability studies for the JPL Space Flight Operations Center, plans for technology transfer, and potential applications of SHARP and related artificial intelligence technology to telepresence operations. The application of SHARP to Voyager telecommunications was a proof-of-capability demonstration of artificial intelligence as applied to the problem of real-time monitoring functions in planetary mission operations. A companion report (JPL Publication 90-21) provides an overview of the design and functional description of the SHARP system as it was applied to Voyager.					
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